NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

PIPELINE ACCIDENT REPORT

PHILADELPHIA GAS WORKS
NATURAL GAS PIPELINE RUPTURE,
EXPLOSION, AND FIRE
PHILADELPHIA, PENNSYLVANIA
MAY 11, 1979

NTSB-PAR-79-3

UNITED STATES GOVERNMENT

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16. Abstract

At 3:05 p.m., e.s.t., on May 11, 1979, two almost simultaneous explosions and an ensuing fire destroyed three buildings near the intersection of Tacony and Margaret Streets in Philadelphia, Pennsylvania. Seven persons, including a Philadelphia Gas Works (PGW) employee, were killed, 19 persons were injured, and several adjacent rowhouses were damaged. The explosion also caused a section of Margaret Street to cave in, exposing a large cavern under the paved surface.

The National Transportation Safety Board determines that the probable cause of the accident was the sagging and breaking of an 8-inch, cast-iron gas main, due to the undetected erosion of the soil support under it, resulting in the migration of leaking gas into adjacent buildings where it was ignited by an undetermined source.

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Adopted: September 27, 1979

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SYNOPSIS

At 3:05 p.m., e.s.t., on May 11, 1979, two almost simultaneous explosions and an ensuing fire destroyed three buildings near the intersection of Tacony and Margaret Streets in Philadelphia, Pennsylvania. Seven persons, including a Philadelphia Gas Works (PGW) employee, were killed, 19 persons were injured, and several adjacent rowhouses were damaged. The explosion also caused a section of Margaret Street to cave in, exposing a large cavern under the paved surface.

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INVESTIGATION

The Accident

From 8:20 a.m. to 2:25 p.m., on May 11, 1979, a PGW serviceman was routinely replacing gas meters at buildings near the intersection of Margaret and Tacony Streets in Philadelphia. During part of this time, the serviceman's company vehicle was parked in front of 2302 Margaret Street. (See figure 1.) The serviceman crossed the intersection many times, but he did not detect any gas odors and no one reported any gas odor to him. The serviceman left the area after completing his work.

At 2:30 p.m., a gas pressure recorder which was connected to the gas system that ran under Margaret Street, and located 1 1/2 blocks from the intersection, indicated that the pressure had dropped from 6 to 3.6 inches of water column. (See figure 2.) This information was telemetered into the PGW distribution department dispatcher office where an alarm sounded. A pressure specialist was dispatched to the location 1 1/2 blocks from the accident site. He checked the pressure chart which indicated a failure somewhere on the gas main. The chart showed the pressure drop in inches of water column and the time of the drop in pressure. The pressure-recording chart was found to be 7 minutes slow, which meant that the indicated 2:23 p.m. pressure drop actually occurred at 2:30 p.m. While the specialist was checking out the equipment, the explosion occurred.

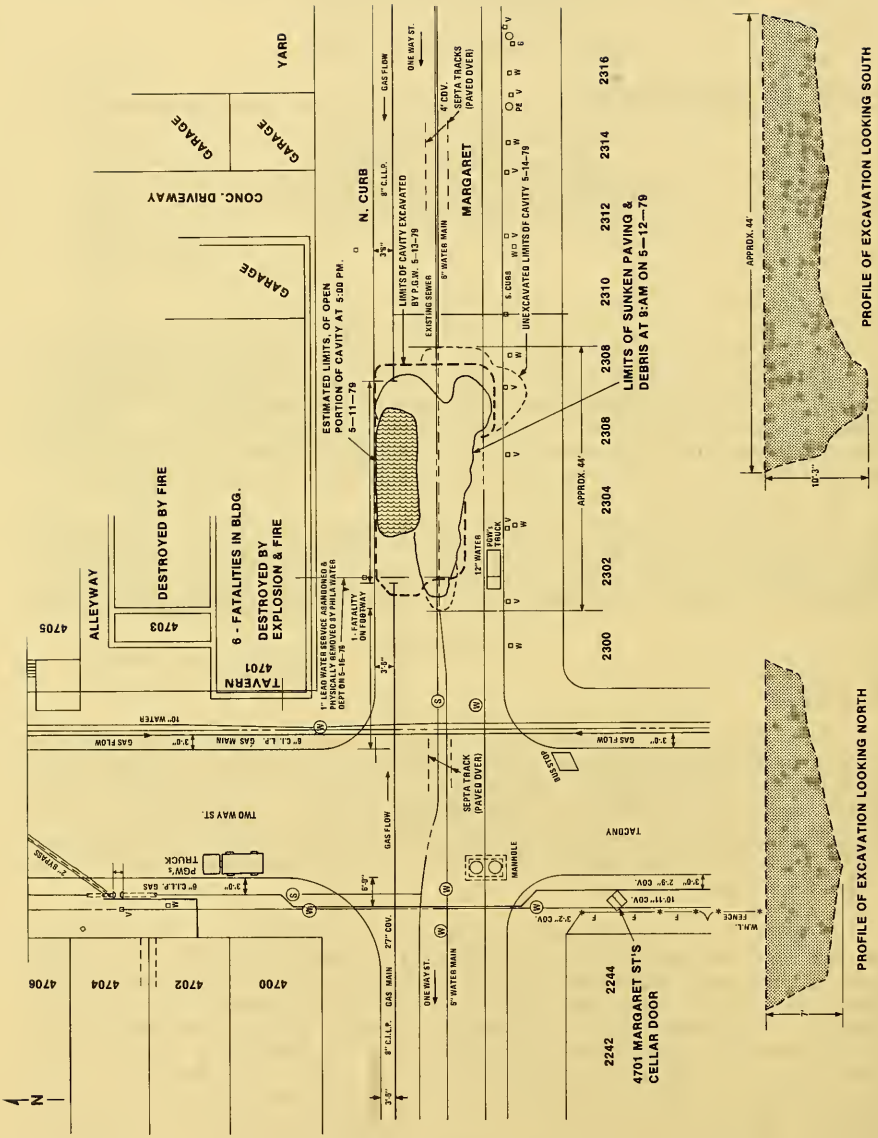


Figure 1. Plan view of accident site.

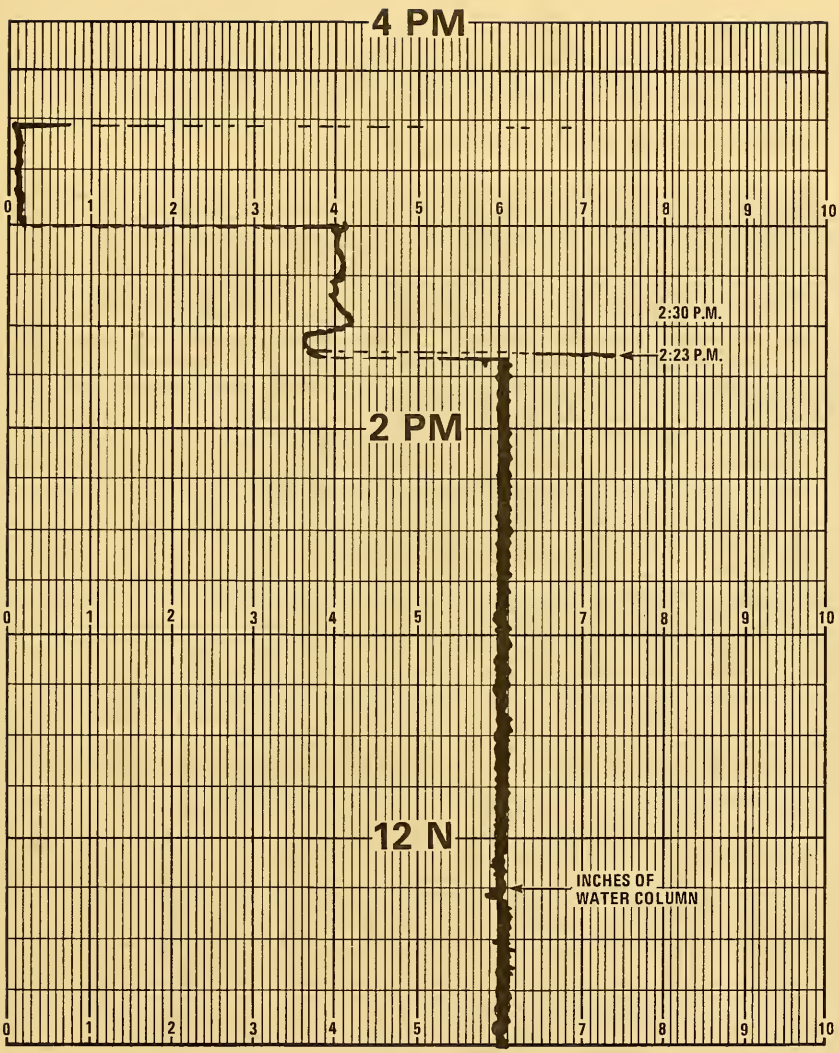


Figure 2. Pressure-recording strip chart.

About 2:45 p.m., a bus driver stopped his bus on Margaret Street near the intersection to discharge passengers. As he opened the bus doors he detected a heavy odor of gas that caused his eyes to water. He closed the doors, drove the bus from the intersection, and stopped in the middle of the next block. He left the bus, alerted some area residents, and asked if someone would call the gas company. The driver then returned to the bus and drove out of the area.

At 2:47 p.m., the telephone service section of PGW received the first telephone call reporting a strong odor of gas in the 4700 block of Tacony Street near the intersection. This report was transmitted immediately to the PGW customer service department. Another PGW serviceman, who had been working 9 to 10 blocks from the site, was contacted by radio at 2:54 p.m. and ordered to investigate the report. By 3 p.m., the serviceman arrived at the intersection, parked his truck across from the tavern on Tacony Street and hurried to take a gas reading in a manhole located in the southwest corner of the intersection. (See figure 1.) Immediately after taking the reading, he looked north and saw two PGW supervisors arriving on Tacony Street. He ran to meet them and reported a 100-percent lower explosive limit (LEL) reading on his combustible gas indicator (CGI). The supervisors told him to check the houses for gas leaks. Following the instruction, he entered the tavern and seconds later the building exploded.

The explosion, followed rapidly by a smaller explosion, occurred at 3:05 p.m., 18 minutes after PGW was first notified of the gas odor. It destroyed the building containing the tavern and an apartment; an adjacent rowhouse; and a garage behind the buildings. All of the buildings caught fire. The roof of the building that contained the tavern was blown up and off, slid into the street, and hung over a 12-foot-high pile of debris that partially covered the sidewalks. A section of Margaret Street beside the destroyed buildings caved in from the weight of the debris.

Immediately after the explosions, the PGW personnel began alerting and evacuating persons in the area. Heavy gas concentrations were evident in some of the evacuated buildings. PGW personnel broke windows and opened doors in nearby buildings to free the gas.

At 3:07 p.m., the Philadelphia Fire Department (PFD) received the first fire alarm followed by a second alarm at 3:14 p.m. Units of the PFD arrived at the site at 3:12 p.m., and immediately began fighting the fire. (See figure 3.) PGW personnel discussed the situation with the firefighters and planned the method of extinguishing the fire. The firefighters were careful not to flood the basement of the tavern because of the possibility of drowning anyone trapped in the debris; this action delayed extinguishing the fire. To control the gas-fed fire, the PGW crewmen started injecting grease 1/ into the gas main and service lines at 3:40 p.m., and at 4:50 p.m. the flow of natural gas at the intersection was stopped and the fire went out.

1/ A procedure where grease is injected into the gas service lines or gas mains to shut off the flow of gas in low-pressure systems. "Greasing off" service lines and mains is a faster process of stopping gas flow than the inflated bag method and is used generally in emergencies. After the emergency, depending on the amount of grease used, the affected gas main or services are abandoned, replaced, or blown clean. The inflated bag method takes longer to accomplish, but it does not leave any residues in the lines afterwards.

Figure 3. Firefighters controlling the fire in debris of buildings at 4701 and 4703 Tacony Street.

During this time, the rubble from the destroyed buildings was removed by a crane and deposited in the hole in Margaret Street. This was done rapidly in an attempt not to cover the entrance to the tavern and to allow rescuers to reach any persons still alive in the building. The weight of the rubble caused more of the road to collapse; the hole eventually became 44 feet long, 20 feet wide, and 10 feet deep. (See figure 1.) The cavern was approximately 4,780 cubic feet in volume.

At 5:12 p.m., PGW personnel opened the sewer manhole at the intersection of Melrose and Margaret Streets and found that a large volume of water without mud or debris was flowing through the sewer. The water clarity and composition indicated that the sewer was intact; no sewer wall breaks were visible.

At 7:30 p.m., while the search for survivors continued, PGW customer service crews continued the gas odor survey of all houses near the accident site. At 9:45 p.m., the PGW distribution crew completed cutting and capping all natural gas mains leading to the intersection. Six "greased off" locations were capped. (See figure 4.)

At 12:01 a.m., on May 12, 1979, the PGW crews completed the installation of the 2-inch bypasses necessary for the restoration of gas service to the area residents. Gas service to 57 customers had been interrupted as a result of the accident.

By the next morning seven bodies had been removed from the rubble. Six of these persons, including the PGW serviceman who had been checking for gas odors, had been trapped in the tavern at 4701 Tacony Street. The seventh person was crushed by debris outside the tavern. No one was in the rowhouse at 4703 Tacony Street at the time of the accident.

Injuries to Persons

Injuries	Operating Personnel	Other
Fatal	1	6
Nonfatal	0	19

Damage to Pipeline

When the hole was cleared of debris and the water was pumped out, investigators found that the 8-inch, cast-iron gas main below the street was broken in three places. (See figure 5—Profile.)

Other Damage

A 6-inch, cast-iron water main in the hole was broken in five places. (See figure 6.) The water main had been installed in 1941 with 4 feet 3 inches of cover. The deepest break in the water main occurred where the main crossed above an 8-inch sewer lateral from a rowhouse. At this point one end of the broken main had dropped 6 feet below its original horizontal position, and had severed the 8-inch sewer lateral connection with the sewer main. (See figures 6 and 7.) The oval-shaped, 3-foot by 2-foot brick sewer was very old, but was found to be intact in the

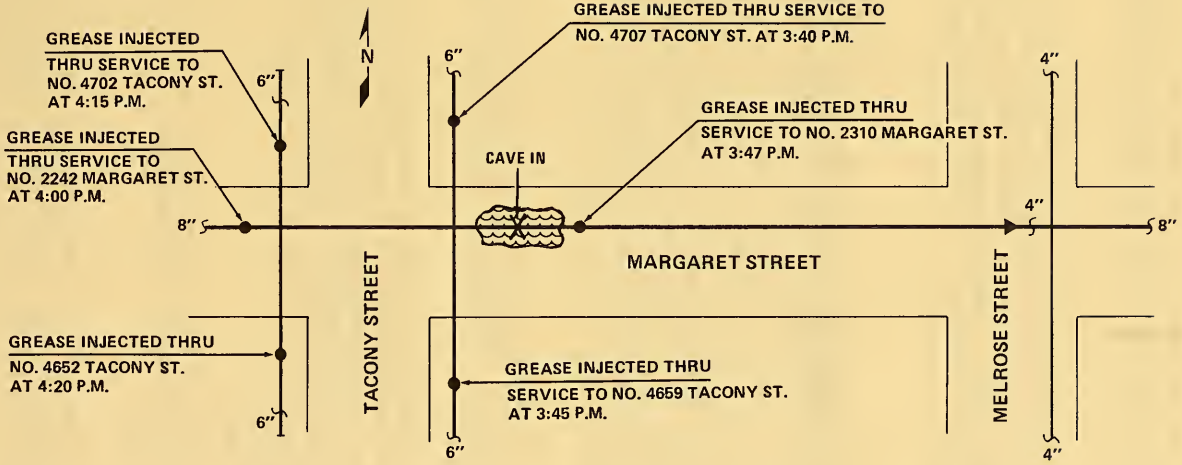


Figure 4. Grease injection locations.

area. A television camera inserted into this sewer and moved along its interior confirmed its integrity. Several of the 8-inch sewer laterals were later found to be broken off where they entered the sewer main; however, this was not detected by the television camera.

The explosions and fire destroyed the two buildings at 4701 and 4703 Tacony Street and a garage. Thirty other dwellings and several vehicles were damaged by flying debris; window breakage was widespread within a 1-block radius of the accident. The explosion was powerful enough to blow a heavy metal cellar door that had been located on the sidewalk in front of the tavern, 80 feet diagonally across the intersection.

Pipeline System

The 8-inch, cast-iron gas main pipe with bell and spigot joints was installed in 1899 in 12- and 16-foot lengths and was buried with approximately 3 feet of cover. The joints were sealed with cement and jute. There are no records of the pipe specifications. The main was operating at an average pressure of 6 inches of water column (about 1/4 psig) when the accident occurred. This type of pipe, with unreinforced bell and spigot joints is limited by Federal regulation (49 CFR 192) to an operating pressure of 25 psig. There were no pressure test records for this pipe. Most of the original gas service lines were tapped directly into the main. There had been no reports of breaks or leaks in the main in this area before this accident. The pressure recorded on the chart had been constant. At the accident site, the low-pressure, integrated, multiflow gas system was fed by mains from four directions.

In the last 5 years, 215 pressure regulator alarms were activated on the PGW system. However, not all of these alarms indicated pipe failures; some represented vandalism, some equipment malfunctions, some electrical failures, and some telephone line problems.

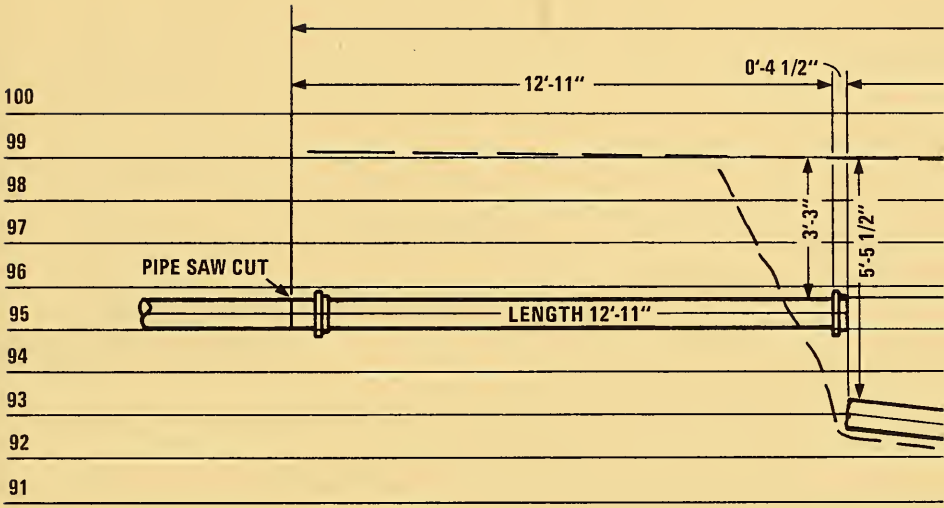
PGW is a municipal gas utility wholly owned by the city of Philadelphia and operated by the Philadelphia Facilities Management Corporation, a nonprofit corporation recognized and existing under the laws of Pennsylvania. PGW has a policy of assisting fire departments at the scene of a fire or explosion involving natural gas. PGW personnel worked with the PFD at the site of this accident to coordinate the evacuation and ventilation of nearby buildings.

Meteorological Information

At the time of the accident it was raining and the winds were lightly blowing from the east. The temperature was in the mid 80's.

Fire

The fire was intense, fueled by escaping natural gas and the dry timber of the old buildings. Firefighters did not use all of the fire hoses available to extinguish the fire immediately because they did not want to cause anyone trapped in the rubble to be drowned. The fire was not extinguished until 4:50 p.m. when the flow of gas was shut off.


100
99
98
97
96
95
94
93
92
91
12'-11"
0'-4 1/2"
3'-3"
5'-5 1/2"
PIPE SAW CUT
LENGTH 12'-11"

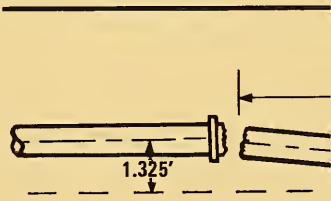
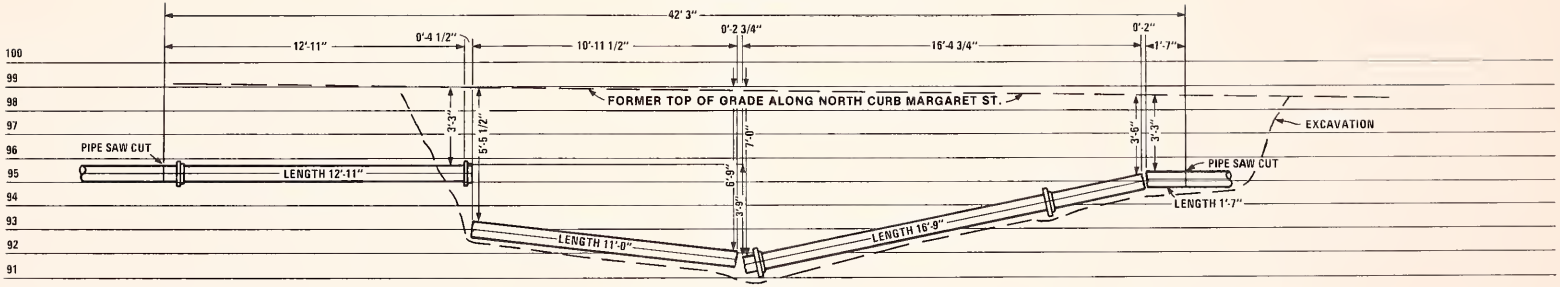

1.325'

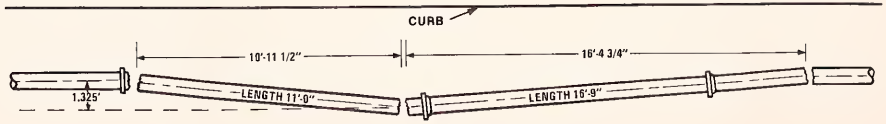
FIGURE 5.

PROFILE VIEW LOOKING NORTH 8'' CAST IRON GAS MAIN

ELEVATIONS TAKEN 5—12—79



PLAN VIEW OF DAMAGED GAS MAIN



MARGARET ST.

PRO

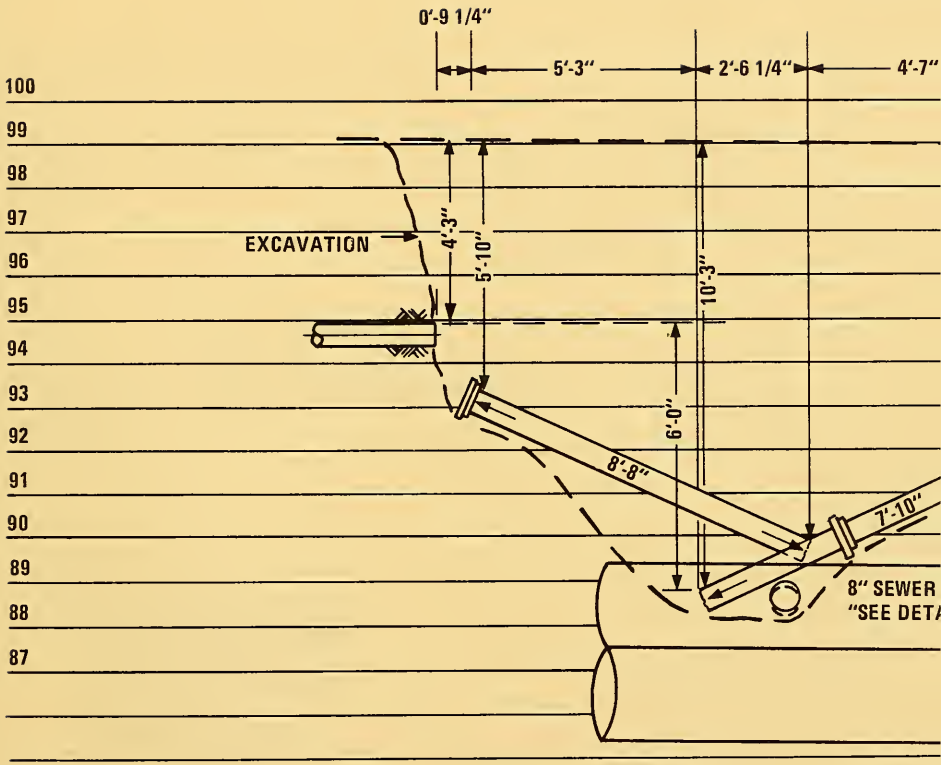
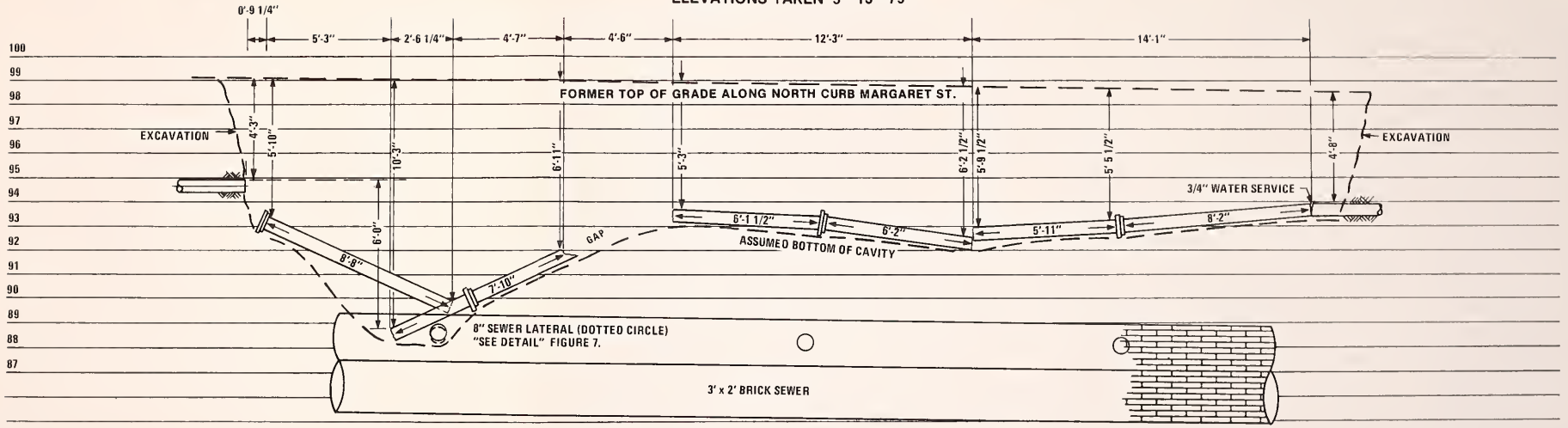

0'-9 1/4"
5'-3"
2'-6 1/4"
4'-7"
100
99
98
97
96
95
94
93
92
91
90
89
88
87
EXCAVATION
4'-3"
5'-10"
10'-3"
6'-0"
8'-8"
7'-10"
8" SEWER
"SEE DETA

FIGURE 6.
PROFILE VIEW LOOKING NORTH 6'' WATER & 3' x 2' SEWER
ELEVATIONS TAKEN 5—13—79



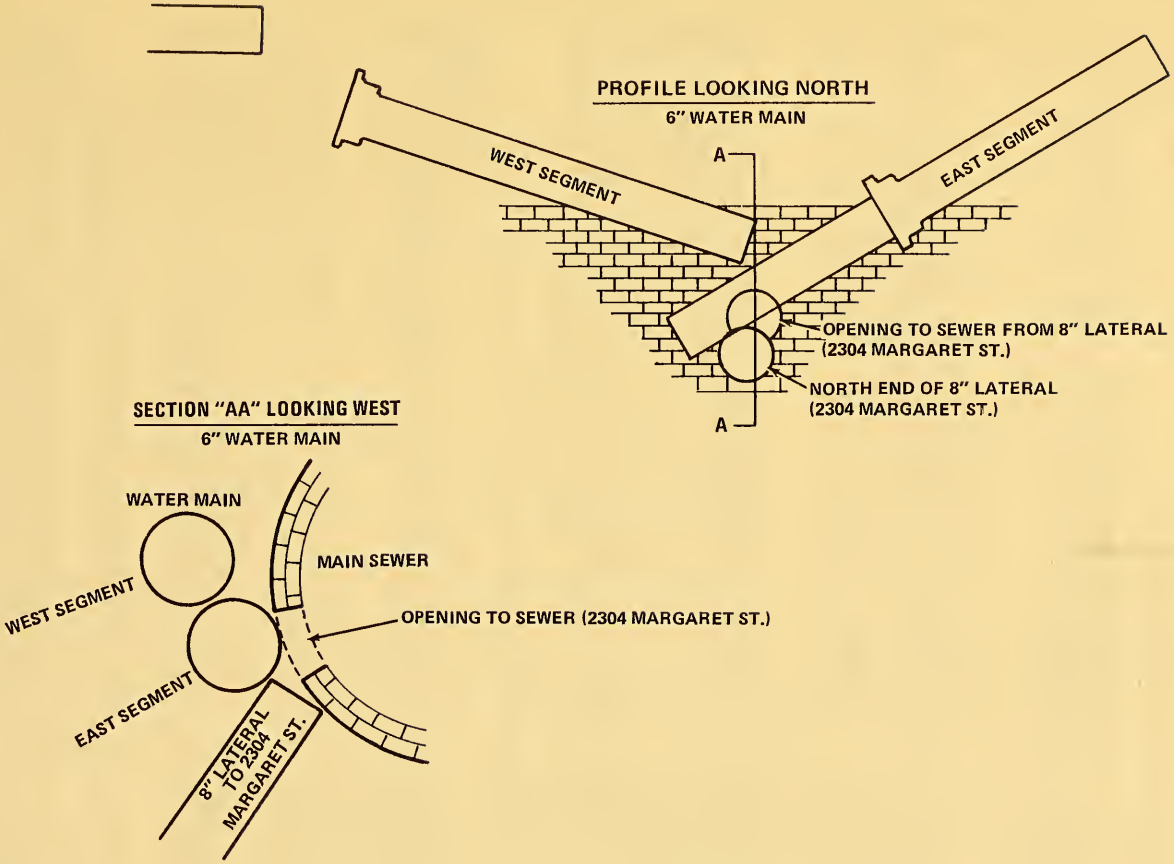


Figure 7. Detailed profile view of water main section.

Medical and Pathological Information

All seven persons died from burns and shock. Nineteen persons were injured by flying debris and broken glass. The more seriously injured were taken to the nearest hospital and treated.

Survival Aspects

Efforts to rescue the seven trapped persons were hampered by the fire. At 3:08 p.m., a man with burns over 30 percent of his body crawled out of the wreckage. Firefighters assisted him to an ambulance, and then cleared debris from the area where the victim emerged to seek others who might still be alive. The rubble was carefully removed from the basements of the building during the search for survivors. The last body was recovered at 4:15 a.m. on May 12, 1979.

Tests and Research

When the gas main was uncovered, the pipe to the east was lying at a slight angle from the horizontal. Excavation to the west exposed two breaks in the line, one end of this broken section was 3 feet 9 inches below its former horizontal position. (See figure 5—Profile.) Further excavation to the west revealed a third break about 11 feet west of the second break. The gas main had shifted laterally a total of 1.325 feet from its original position. (See figure 5—Plan View.) The broken main ends and segments of the water main were cut off and visually examined by a Safety Board metallurgist. The pipe was also sent to the National Bureau of Standards for further metallurgical examination.

Metallurgical examination of the gas main revealed the following:

1. The fracture face was coated with corrosion products, some of which were removed when cleaned ultrasonically for 10 minutes with a detergent. Most of the remaining corrosion was removed with buffered hydrochloric acid. The corrosion products on the fracture face appeared to be superficial, indicating that the fracture was recent.

2. Very small amounts of graphitization were detected on the outside pipe surface next to the fracture.

3. The 10 Rockwell K hardness (RKh) measurements that were made were essentially all the same. The average RKh value was 92.2. This value is the approximate equivalent of a Brinell hardness number (Bhn) of 156, which is considered to be a reasonable value for gray cast iron.

4. The pipe appeared to have been pit cast, not centrifugally cast. Centrifugally cast pipe was not available when the pipe was manufactured.

5. The scanning electron microscope examination of the fracture revealed the primary fracture mode was "cleavage," indicating a low ductility or brittle fracture. This type of fracture is common in gray cast iron.

Metallurgical examination of the 6-inch, cast-iron water main revealed the following:

1. The three fracture faces submitted were covered with corrosion products. The fractures were cleaned ultrasonically with a detergent followed by ultrasonic cleaning with buffered hydrochloric acid. Some of the corrosion product adhered tightly to the fracture face, and much of it remained on the surface after the cleaning process.

2. Because of the difficulty in removing the corrosion product from the fracture and because of the corrosive attack of the fracture features, it appeared that the the pipe had been fractured for some time.

3. After cleaning, part of one of the fracture face was examined by the scanning electron microscope. Corrosion had eliminated many of the fracture features, but the fracture mode appeared to be cleavage.

4. Ten RKh measurements were taken on transverse sections through the pipe. The average of these 10 measurements was RKh 92.8. This value is the approximate equivalent of a Bhn of 159, which is considered to be a reasonable figure for gray cast iron.

Other Information

Street cave-in. — Examination of the caved-in section of the street in front of the destroyed buildings revealed the following:

1. The road surface on Margaret Street was asphalt-tar over a layer of cobblestone or Belgian block over a concrete layer which at one time had been the street's surface.

2. Trolley tracks had been installed in the cobblestone some years ago, and the two tracks spanned the open ditch in an east-west direction slightly south of the centerline of the excavation.

3. The cavity beneath the road appeared to have been in existence for a considerable time before the road collapsed. The trolley track apparently had supported the road surface and all the vehicular traffic on the road up to the time of the cave-in. (See figure 8.)

4. The position of the gas main and the water main at the east and west ends of the cave-in indicated that they had been hanging in the cavity unsupported from beneath for an indeterminate time.

5. The condition of the sewer main was good with no breaks or leakage in the area excavated.

6. Six sanitary sewer laterals were excavated and examined. These laterals served the rowhouses and tavern adjacent to the cave-in. In general, the laterals were not in good condition; three of them appeared to have been disconnected from the sewer main for some time. (See figure 9). The ground around these laterals contained sewer sludge.

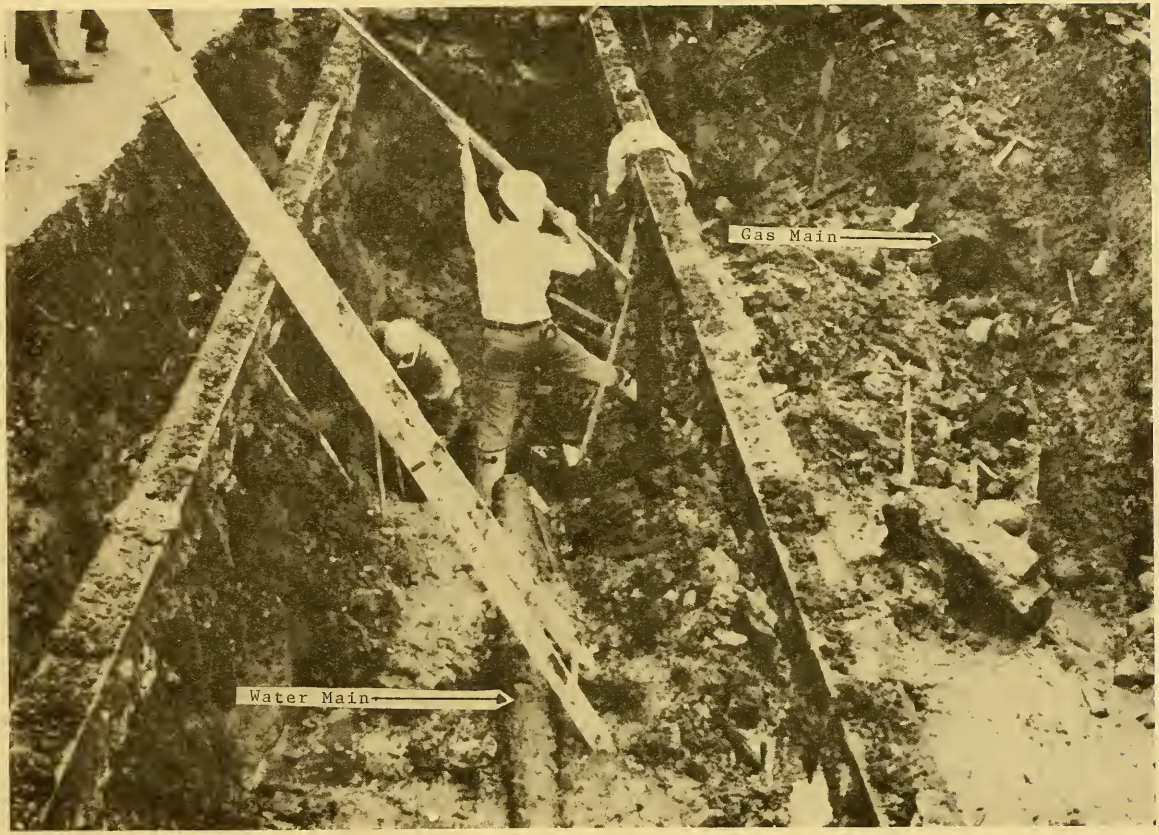


Figure 8. Partial view of cavern over which trolley track had supported pavement.

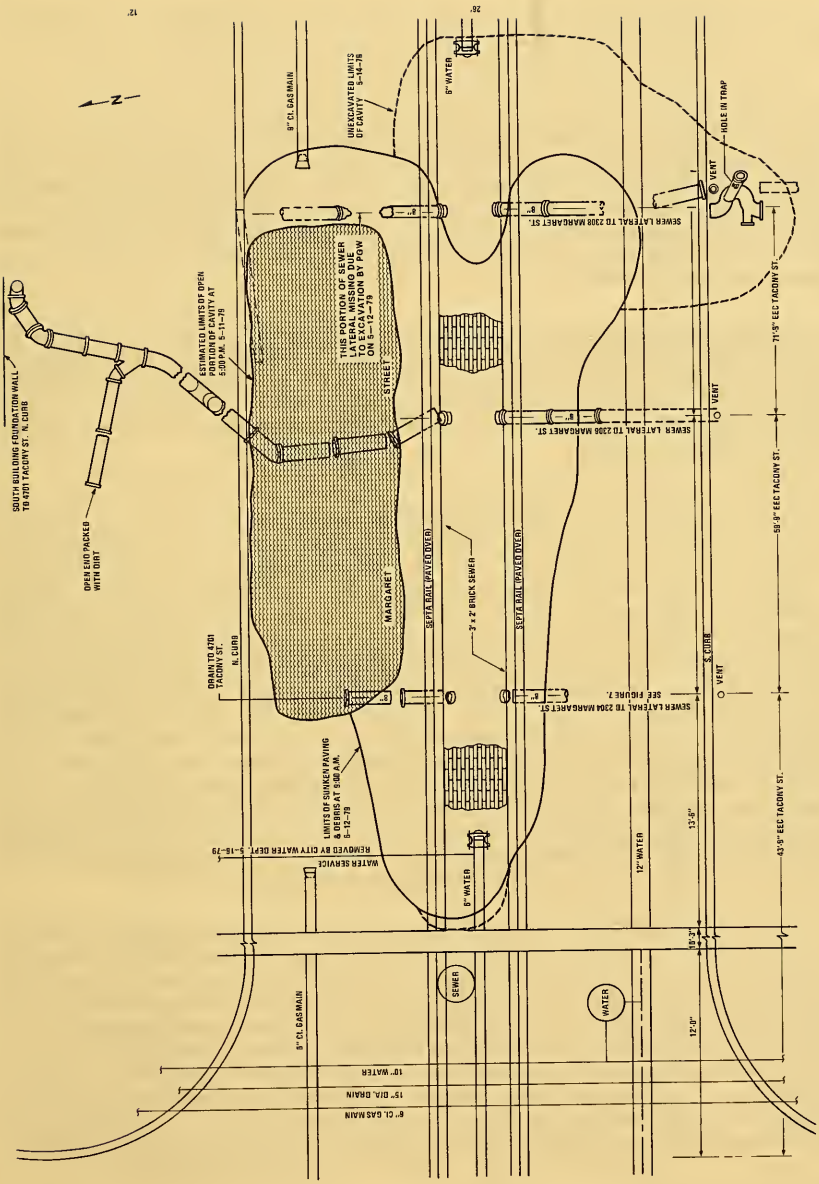


Figure 9. Plan view of initial cave-in with adjacent damaged sanitary sewer laterals.

7. Westbound buses passed the intersection of Tacony and Margaret Streets at approximately 20-minute intervals before the explosion.

Water pressure. — A check of the water and sewer records indicated that there had been no complaints of blocked sewer drain or low-water pressure from the immediate area residents. However, the tavern did have low water pressure on May 10 and May 11, 1979. A part-time bartender in the tavern and a postman, who were in the building the day before and the day of the explosion, said that the tavern was having problems with its water pressure. The bartender had notified the city water department. On May 11, 1979, personnel from the department checked the problem and left, telling the bartender that they would return. The explosion and fire occurred in the afternoon.

Calculations of gas loss. — Computerized calculation of gas flow showed a total of 152.76 MCF 2/ of gas lost from 2:30 p.m. to 4:50 p.m. (See appendix B.) From 2:30 p.m., the time of the failure, until 3:05 p.m., the time of the explosion, a total of 50 MCF of gas entered the cavity beneath the street. It took approximately 3 minutes to fill the estimated 4,780-cubic-foot cavern at a rate of 1,619 cubic feet per minute.

ANALYSIS

The examination of the cave-in revealed that the large cavern had been in existence for a long time and had been created by a slow erosion process. The poor condition of the three sewer laterals and of the soil around them leads the Safety Board to conclude that seepage from these laterals contributed to the erosion that created the cavern. The openings in the sewer main caused by the broken laterals, allowed sewer backup during periods of heavy rain to escape and erode the immediate area. Water escaping from the fracture in the water main, which tests indicated had existed for some time, also probably contributed to the erosion. The break in the water line was not complete; it was probably more of a fissure which let water escape under pressure and helped to erode the cavity. Had the water pipe broken completely, water pressure to the area would have been disrupted, residents would have complained of no water or low water pressure, and the break would have been detected and repaired within a few hours.

The 8-inch, cast-iron gas main, although installed 80 years ago, was found to be in good condition, without extensive corrosion, and within definition for gray cast iron of that era. The light corrosion on the fractured pipe face, the ease with which it was removed, and the lack of corrosive attack on the fractured faces of the pipe itself indicated a very recent break. Cast iron when exposed to the elements will often show traces of rust in a matter of hours. The pipe, in 12- and 16-foot sections, had hung unsupported for a long time in a span until it snapped and broke, due to a combination of factors such as the pipe's own weight, traffic vibrations, pavement settling, or other unknown outside forces. No reports of gas odor had been received recently from this area, no gas pressure reductions had

2/ MCF is an industry abbreviation for 1,000 feet.

been noticed, and the pressure-recording chart 1 1/2 blocks away had been constant in the recent past. Therefore, the Safety Board concludes that the gas main collapsed at 2:30 p.m. on May 11, 1979, as indicated by the rapid drop from 6 to 3.6 inches water column shown on the pressure-recording chart.

After the main broke, gas at approximately 6 inches water column pressure began flowing into the cavern under Margaret Street at an estimated gas flow rate of 1,619 cubic feet per minute. The cavity was filled with gas in approximately 3 minutes. Once filled and unable to escape rapidly because of the paved road above, the gas began to build up pressure and migrate through the foundation of the tavern and also up through the storm drain to the road above. At approximately 2:45 p.m., 15 minutes after the break, enough gas had gained access to the street level to alert the bus driver.

The liaison between PGW and the Philadelphia Fire Department resulted in prompt evacuation of the area and an effective lowering of the lower explosive limit in the adjacent houses by ventilation. These actions prevented secondary explosions which could have caused additional damage and loss of life.

A bag inserted in the gas main and inflated is a customary method of stopping gas flow in low-pressure systems. However, this method is time-consuming because it requires excavation of the main, cleaning it, installing a pipe tapping unit, cutting out the top, and inserting and inflating the bag. The effective "greasing off" of the multiflow gas system at the leak site was a better procedure in that it saved valuable time.

CONCLUSIONS

Findings

1. The large cavern under Margaret Street, which contained the gas, sewer, and water mains had been created over a period of time by soil erosion.

2. Seepage from the openings in the main sewer caused by the broken laterals contributed to the erosion that caused the cavern.

3. Water escaping from the water main also probably contributed to the erosion.

4. The water main probably had been cracked some time before the accident as revealed by metallurgical analysis which showed adhesive corrosion products on the fracture faces and corrosion of the fracture face itself. Complete severance of the water pipe occurred at the time of the gas main failure.

5. The gas main had been undermined by the soil erosion and had been hanging unsupported for a long time before it broke.

6. The gas main failed at 2:30 p.m. when it broke into three pieces from one or a combination of factors such as the pipe's own weight, traffic vibrations, pavement settling, or other unknown outside forces.

7. Liaison between PGW and the Philadelphia Fire Department resulted in the prompt evacuation and effective ventilation of affected houses in the accident area.

8. Prompt "greasing off" of the gas mains by PGW prevented additional migration of natural gas to the affected area.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the sagging and breaking of an 8-inch, cast-iron gas main, due to the undetected erosion of the soil support under it, resulting in the migration of leaking gas into adjacent buildings where it was ignited by an undetermined source.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board recommendated that the American Gas Association:

"Advise its member companies of the circumstances of this accident and of the prompt and effective coordination betwen the gas company and the fire department and urge them to review their emergency practices and procedures, particularly those concerning evacuation and liaison with fire and police departments to insure that coordination is planned adequately for similar accidents. (Class II, Priority Action) (P-79-59)"

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ ELWOOD T. DRIVER
Vice Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PATRICIA A. GOLDMAN
Member

/s/ G.H. PATRICK BURSLEY
Member

September 27, 1979

APPENDIX A

INVESTIGATION

The National Transportation Safety Board was notified of the accident at 4:50 p.m. on May 11, 1979. The Safety Board immediately dispatched two investigators from its Washington, D.C., headquarters to the accident site. Upon arrival at the scene, the Safety Board investigators took charge of the investigation.

APPENDIX B

Excerpts from PGW Report on the Calculation of Gas Loss on May 11, 1979 from 2:30 P.M to 4:50 P.M.

A "skeletonized" version of the low-pressure system in the vicinity of Tacony and Margaret Streets was modeled on a digital computer using Dr. M.A. Stoner's "Gas Steady State (GASSS) Network Analysis Program through time-sharing facilities of the National Computer Software Systems (NCSS). The Pole Low Pressure Gas Equation was used in the modeling of the system.

This "skeletonized" system consisted of the principal large low-pressure mains transporting gas to and from the area together with the network of smaller mains in the immediate vicinity of Tacony and Margaret Streets. Since May 11, 1979 was a warm day (85° F recorded at 2 p.m. at Richmond Plant) and considering the time of day (2 p.m.) no large gas demand such as heating or cooking would be expected. We, therefore, concluded that inclusion of small gas mains (6-inch and smaller), except in the immediate vicinity of the break, would have no meaningful effect on the problem.

The first computer run simulated conditions in the system at 2:25 p.m., immediately before the break. Matching the actual recording gauge pressures at the outlet of the regulator stations and at the test points in the study area established the gas flow and loading in the system.

The second computer run simulated conditions at 2:30 p.m. the time of the break. A load point was established at the location of the main break and the load at this point, which would be the same as the gas escaping from the broken main was calculated by the computer when all the actual pressures were matched.

The third computer run simulated conditions at 3:30 p.m., which was the time when the Kensington and Torresdale Streets regulator loaded to 7.6 inches water column because the control point pressure at Melrose and Orthodox Streets dropped to 3.9 inches water column. The flow of gas from the main break was at its greatest at this time and was calculated by the computer when all the actual pressures were matched.

The fourth computer run simulated conditions at 3:55 p.m., immediately after the flow of gas from the 6-inch main on the east side of Tacony Street was stopped by the injection of grease north of Margaret Street at 3:40 p.m. and south of Margaret Street at 3:45 p.m. The injection of grease into the 8-inch main on Margaret Street east of the break point at 3:47 resulted in a partial stoppage of gas flow. The resistance to the flow of gas from the main break because of the grease injection into the 8-inch main was represented by a short length of small-diameter main. By varying the diameter of this main until all the actual pressures were matched, the computer calculated the volume of gas lost at this time.

The fifth computer run simulated conditions at 4:07 p.m., immediately after grease was injected into the 8-inch main west of Tacony Street. This grease

injection along with the previous injections in the 6-inch main on the east side of Tacony Street stopped virtually all gas flow from the west. The small amount of gas still coming from the break again was calculated by the computer in the same manner as the fourth computer run.

In our judgment, there was no need for further computer runs to calculate the additional loss of gas between 4:07 p.m. and 4:50 p.m. when complete shutdown was accomplished, since this could be established from the time-flow plot of the compter runs made. (See figure 10.) The time-flow plot shows a total of 152.76 MCF (1,000 cubic feet) of gas lost from 2:30 p.m. to 4:50 p.m.

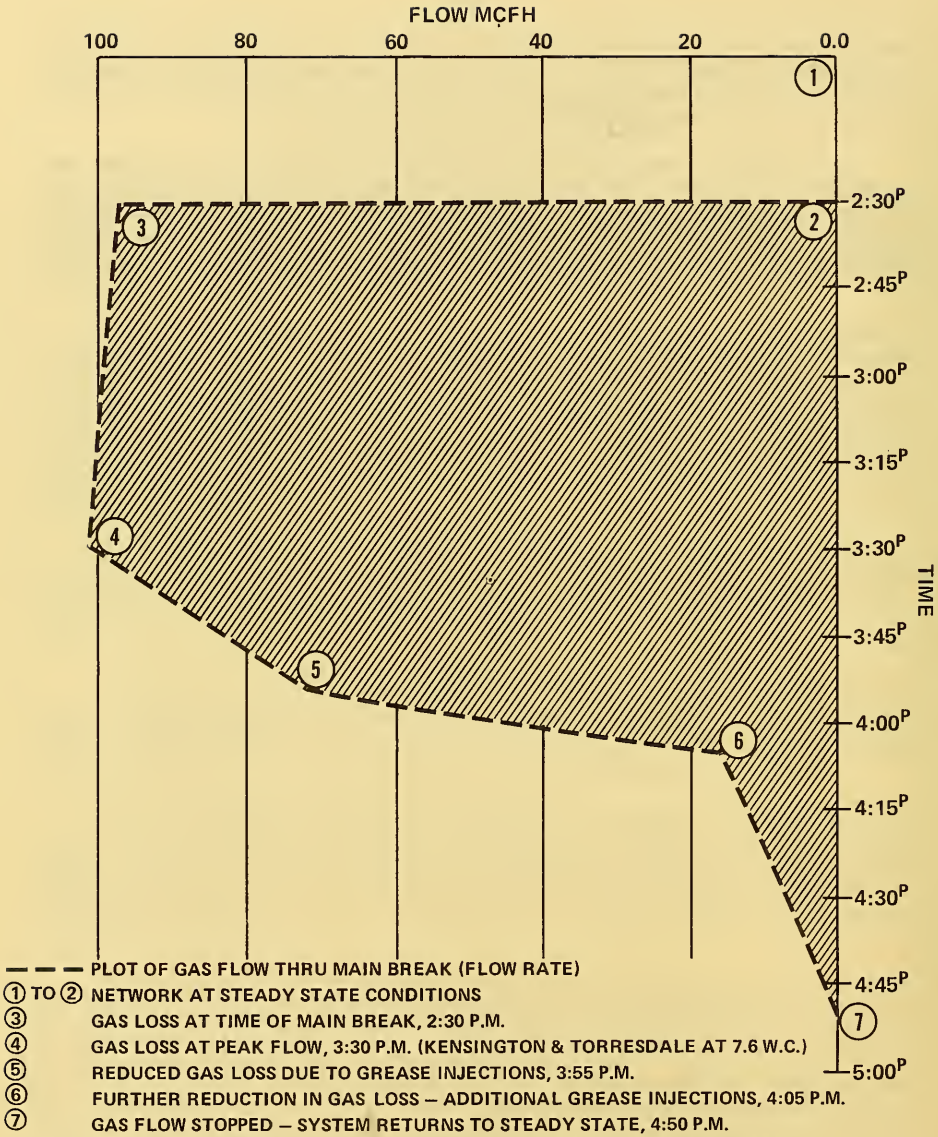


Figure 10. Time-flow plot of gas loss.

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